# EFFECT OF THE PRESENCE OF DISTRIBUTED GENERATION ON THE STUDIES OF OVERCURRENT PROTECTION COORDINATION

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## ABSTRACT

*The presence of day by day more distributed generators connected at distribution levels, modifies the behavior of the protection system under short-circuit conditions in aspects such as: initial magnitude of the fault current, temporary variation of the fault current magnitude, and fault current flow direction. The study was made in analytic and experimental form, using MATLAB Simulink and equipment of a teaching laboratory. The overcurrent protection coordination study is carried out more based on the concept of specific energy as time function* $I^2t\ (t)$ *rather than based on the time-current characteristics I (t). The penetration values can be identified, for which it is necessary to use the methodology based on specific energy. It is concluded that the method using specific energy is something more laborious but it allows making the coordination study in precise form.*

## INTRODUCTION

The specific characteristics of the distribution system that are dissimilar in the different countries indicate the protection type in use. The presence of day by day more distributed generators (DG) connected at distribution level impact the traditional distribution system exploitation rules. The use of DG presents advantages and disadvantages, being one of the main disadvantages the effect on the installed protection scheme, which is in use before the arrival of the DG, with the addition of the much feared island operation [1, 2]. These characteristics lead to the argued measure of demanding the instantaneous disconnection of the DG in presence of any perturbation in the system [3]. The concept that supports this demand is based in that this disconnection transform the distribution system into the previous structure, in what concerns to the system topology (single source) and protection scheme (simple radial system with the elements in series, circulated by the same current). Firstly, the disconnection of all the DG for each possible perturbation is attentive against the maintenance of the curve time - voltage (Grid Codes) and in extreme cases it can cause the collapse of the system for “loss of generation". Besides, the disconnection time is not instantaneous, but of the order of the 40 to 60 ms, durations that are significant for the speeds of the protection devices. This disconnection would leave unnecessarily without electric service to users that could continue fed by the neighboring DG, operating in island. The operation in island presents two fundamental problems, the personal and equipment risks and the out-of-phase reconnection. This last one can be kept in mind by means of the non-rigid connection methodology that has several implementation forms, which are: “double-circuit breaker”, “limiting impedance”, and “series compensator” [4, 5, 6].

On the other hand, the rotational equipment employees as DG should now be protected against high harmonic contents and of unbalance, that before was not necessary since at the levels of traditional generation the mentioned perturbations do not happen.

The introduction of DG in the traditional distribution systems generate a fundamental difference, since the short-circuit current that the sources supply to distribution level is not of constant magnitude any more. The short circuit current given by the synchronous machine possesses three periods clearly defined, denominated sub-transient, transient and permanent, being the fault current of the two first periods variable following an exponential attenuation with time. The short-circuit current of the traditional distribution systems was considered constant, independent of this exponential variation, since the magnitudes of the impedances inserted from the source until the fault location point masked totally this variation. The DG with synchronous machine, connected to the distribution circuit introduces directly these sub-transient and transient currents to the circuit, which are of magnitude that cannot be rejected. A similar phenomenon happens with the induction generator whose short-circuit current also attenuates in time. Furthermore, these forms of variation of the induction and synchronous machines depend on their excitation type [7].

Besides, it is day by day more used the connection of the DG to the distribution system through power electronics which due to the high overcurrent sensitivity of the semiconductor devices, possess protection that is based on limiting the fault current to values from 1.5 to 2 times the rated value, being dependent of the tension - current control scheme of the inverter. In other words, the DG connected through inverters is another source of short-circuit current of magnitude variable (sharply) in time [8, 9]. Must be also taken into account, in case of be applicable, the compulsory disconnection of the distributed sources that is imposed by some standards and utilities [3].

Of this analysis it is concluded that the distributed sources inject to the traditional distribution circuit fault currents that are attenuated in time, either in gradual or abrupt form.

The fault current possesses now several components, one of constant magnitude supplied by the grid and other coming from the DG whose magnitude attenuates in time and whose influence on the total current depends on the penetration level. This aspect should be considered in the calculation or verification of the circuit breakers and fuses rupturing capacities and on the electro-dynamical stresses suffered by the circuit elements circulated by this multi-component short-circuit current.

In the event of operation in island, the fault current component of the grid disappears, therefore the level of this

current will depend on the power of the distributed generation now isolated, what usually significantly reduces the available short-circuit current.
Seeing the problem from the point of view of the distribution system overcurrent protection, two situations are presented:
- Normal, that is to say with grid feeding, plus the collaboration of the distributed sources that leads to higher fault currents and therefore shorter protective device operation time, that can cause the failure of selective coordination scheme (adjusted before the arrival of the DG), but that it does not reduce significantly the protective devices sensitivity.
- Island, without grid feeding and with a considerable reduction of the current intensity that is of concern if the current ceases of being detected by the protective devices.
In numerous publications it is mentioned of the inconvenience in the delay in the performance of the protection, which is not of great concern due to in distribution systems the more used overcurrent protection is based on inverse time-current characteristics. That is to say that with lower current values the protective device operation would take a longer time but the value of specific energy is kept, that is the indicator of the overcurrent damage capacity. What is not so, if a definite-time protection has been used.
The previous paragraphs show the importance that acquires for the present protection coordination analysis the concept of specific energy.
It is common to find in the specialized references expressions such as that the local information of the protection is no longer applicable for distribution systems with DG, proposing the use of much more sophisticated and expensive protection schemes, encouraging to the employment of technologies that in authors' opinion are of unjustified costs [10, 11].
The premise of this work is the maintaining connected of the DG without forgetting the personnel, equipment and system security, modifying the less possible the overcurrent protection scheme of the current distribution systems, reducing to the minimum the required investments.
It is necessary to consider that fuses can not be used in the current flow path between the grid and any DG, but there is the guarantee that the fuse operation shall cause a three-phase opening, due to synchronization problems.
It must be taken into account the possible reverting of the fault current flow in protective devices that traditionally were connected in radial form, that is to say that they were usually circulated by the same current value, situation that can lead to the failure of the selectivity.

## EXPERIMENTAL AND ANALYTICAL STUDY

The study of the problem was made in analytic and experimental form, using MATLAB Simulink and equipment of a teaching laboratory of size corresponding to approximately 10 kW, with the protective devices of appropriate rated values to simulate overcurrent coordination analysis with the mentioned source sizes.

### Experimental study

The short-circuit currents were determined in the electric machines teaching laboratory, using synchronous and induction type generators, whose wave forms are shown in Fig. 1 and Fig. 2 respectively, where can be clearly seen the attenuation already mentioned.

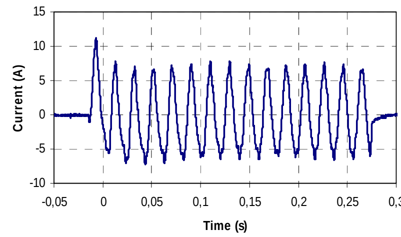


Fig. 1, Short-circuit current of a synchronous machine.

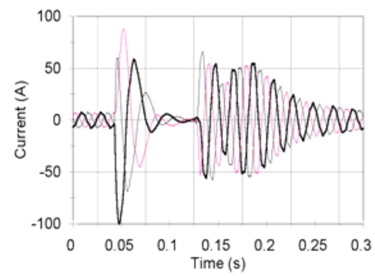


Fig. 2, Behavior of squirrel-cage induction generator excited by remnant magnetism.

Fig. 3 shows the attenuation experimentally determined together with the analytic one calculated by using a simplified procedure based on just three time constants. The time constants were determined in experimental form that corresponds to the following physical phenomena: attenuation of the remnant magnetism, demagnetizing effect of the fault current and attenuation for speed reduction.

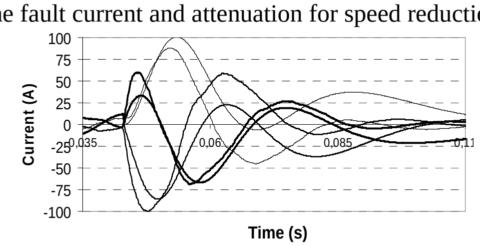


Fig. 3, Comparison of analytical and experimental short-circuit currents of an induction generator.

In specialized references, the control of the short circuit currents supplied by DG with inverters is given, mentioning the reaction time [8, 9].

### Analytical study

Traditionally the characteristic curves of overcurrent protective devices (fuses and circuit breakers) are given in the form of time - current graph, whose typical forms are shown in Fig.4, those that should be translated into time - specific energy curves due to the previously mentioned reasons, as can be seen in Fig. 5.

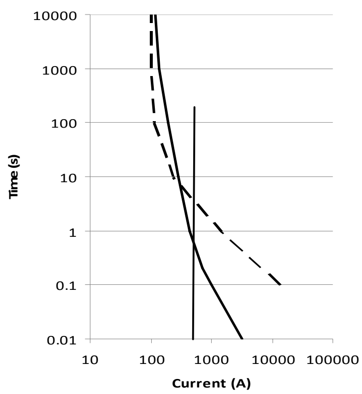


Fig. 4, Time-current characteristics corresponding to a fuse (solid line) and to a circuit breaker (dashed line).

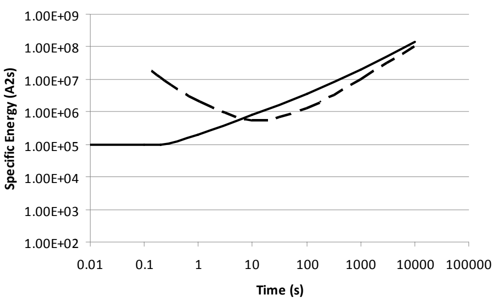


Fig. 5, Specific energy as time functions from fig. 4 for fuse and circuit breaker.

The curves t-I of Fig. 4, have been developed to give the operation time for constant values of current flowing through them, that is to say that for example a current of constant value of 500 A causes the opening of the fuse (IEC 60282) in 0.6 s and the operation of the circuit breaker (IEC 60255) in 3.9 s. If the current was of non-constant magnitude, it did not represent a problem since until this moment the protector and protected devices were strictly in series, being circulated by exactly the same current. Thus its thermal and electro-dynamical effects were comparable.

When the DG was introduced, the coordination stops to be strictly series, for what the non-uniformity of this current is significant since different currents can flow through the protected and protective devices. The solution resides in considering the operation specific energy of the protective devices, compared with the specific energy corresponding to the deterioration of the protected equipment.

In this stage of the analysis, it should be kept in mind a very important characteristic of the protective devices used in the distribution systems, that is the ability to limit or not the fault current. This limitation is shown in the maintenance of a constant $I^2t$ operation value for fault durations shorter than approximately 100 ms (see Fig.5). If the interest resides in that the protective device would not operate, it must be considered an $I^2t$ constant value, since if it is a fuse this should not overcome the pre-arc period, but if it is a circuit breaker it should not gives the opening order. If the definitive interruption is under study, the curve of total operation time should be used (translated into time - specific energy curve), for what to the pre-arc energy the arc energy should be added, or if it is not a limiting current device the energy should be calculated for the fault current up to the next current zero crossing.

In the present work the overcurrent protection coordination study is carried out more based on the concept of specific energy as time function $I^2t$ (t) rather than based on the traditional time-current characteristics I(t).

In Fig. 6 it can be seen the typical variation of short-circuit current as time function of a distribution system with grid contribution, plus collaboration of synchronous generation with a penetration of 25% and with the collaboration of photovoltaic cells whose inverter is limited in 1 s to just 50% of its short-circuit current.

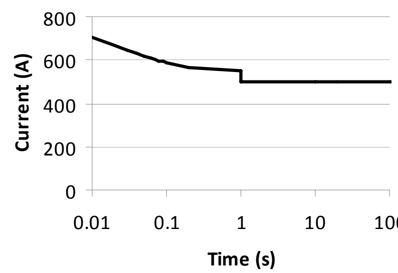


Fig. 6, Short-circuit current supplied by the grid and two DG (synchronous and PV).

According to the relative position of the fault respect to the protection devices (PD) to be coordinated, it is possible that exists or not the mentioned fault current contributions. Fig. 7 shows a simplified circuit from which it can be realized that in the coordination study between the protective devices D3 and D4 for Fault 1, all the sources contribute to the fault due to both devices are strictly in series; therefore the currents through them are exactly the same. The situation is completely different for the study of the coordination for Fault 2 among devices D1 and D5, as also between D2 and D5, where the explained methodology should be used, determining the operating time for D5 before reaching the irreversibility limits of D2 or D1.

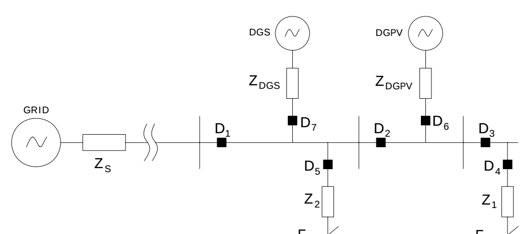


Fig. 7, Distribution system simplified circuit.

Fig. 8 shows the curves of $I^2t$ as time function of the fault current in comparison with that of the protective device, for the first example of coordination D3 (63A)-D4 (40A), both devices circulated by the same short-circuit current, current that cause the D4 protective device operation at 0.04s and the D3 opening at 0.11s, which shows their coordinated operation. Fig. 9 explicit the coordination D1(200A) -D5 (63A) (the coordination is guarantee due to the bigger fuse is circulated just for the grid current instead of the D5, smaller fuse which have the current supply from the three sources), that will operate at 200s and 0.1s respectively. Fig. 10 shows the coordination analysis D2(100A)-D5(63A), indicating the opening time at 8000s y 0.11s respectively.

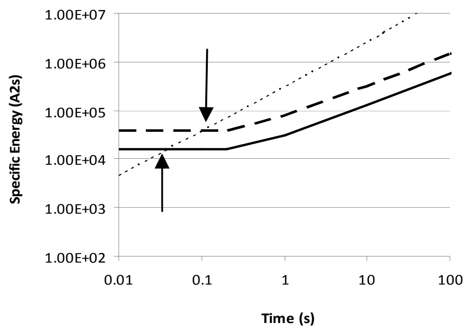


Fig. 8, Specific energies comparison protective devices – fault current (solid and dashed: PD, dotted: current).

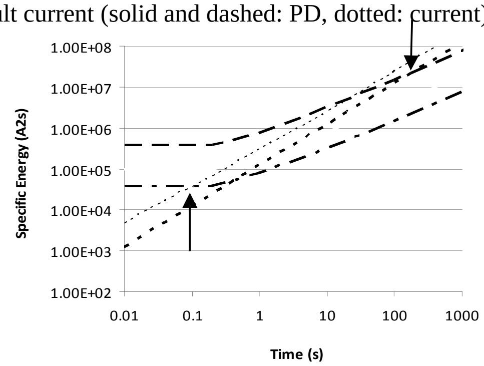


Fig. 9, D1-D5 coordination study by using "specific energy – time" curves (dash-dot and dashed: PD, dotted: current).

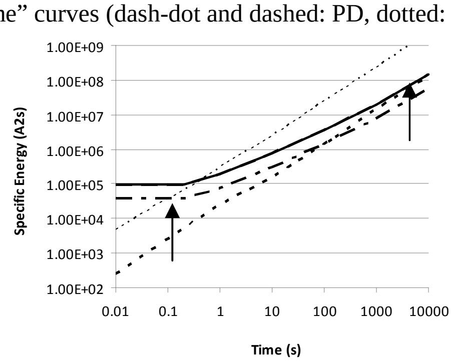


Fig. 10, D2-D5 coordination study by using "specific energy – time" curves (solid and dash-dot: PD, dotted: current).

Penetration limits from overcurrent coordination point of view, can be easily identified, by the application of this methodology based on $I^2t$. The time interval between arrows shown in fig. 8 to 10, is the coordination margin that can be modified by changing the PD rated current or setting and also by modifying the percentile collaboration of each DG.

## CONCLUSIONS

It is concluded that the method using specific energy is something more laborious but it allows making the coordination study in precise form, with dissimilar penetration levels, and having dissimilar DG sources, supplying the coordination time margins.

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